In families where genetic disease has been passed down generation after generation, serious questions arise.

- If someone is a carrier, should they have children knowing that they might transmit the gene?
- How would it feel knowing – or not knowing – if you had the gene?
- How might parents feel when they find out they have passed the gene on to their offspring?
- Is it difficult for people who have genetic diseases to find someone to marry? A job? Life insurance?
- Should employers or insurance companies have the right to know if someone has a genetic disease or is that a medical secret?
- When, if ever, is screening appropriate (getting a genetic test done on an unborn child)?

Exercises

10 Explain why more men are affected by colour blindness than women.

11 Using the C^R and C^W alleles for codominance in snapdragon flower colour, show how two plants could have some white-flowered offspring, some pink-flowered offspring and some red-flowered offspring within one generation.

12 Draw a pedigree chart of the two generations described in exercise 11.

13 Look at the grid below showing the chances that a couple's children might have haemophilia.

a State the genotype of the mother and father.
b State the possible genotypes of the girls and boys.
c State the phenotypes of the girls and boys.
d Who are the carriers in this family?
e What are the chances that the parents' next child will be a haemophiliac?

	X^H	Y
X^H	X^HX^H	X^HY
X^h	X^HX^h	X^hY

Genetic engineering and biotechnology

AHL 4

Assessment statements

4.4.1 Outline the use of polymerase chain reaction (PCR) to copy and amplify minute quantities of DNA.
4.4.2 State that, in gel electrophoresis, fragments of DNA move in an electric field and are separated according to their size.
4.4.3 State that gel electrophoresis of DNA is used in DNA profiling.
4.4.4 Describe the application of DNA profiling to determine paternity and also in forensic investigations.
4.4.5 Analyse DNA profiles to draw conclusions about paternity or forensic investigations.
4.4.6 Outline three outcomes of the sequencing of the complete human genome.
4.4.7 State that, when genes are transferred between species, the amino acid sequence of polypeptides translated from them is unchanged because the genetic code is universal.
4.4.8 Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast or other cell), restriction enzymes (endonucleases) and DNA ligase.
4.4.9 State two examples of the current uses of genetically modified crops or animals.
4.4.10 Discuss the potential benefits and possible harmful effects of one example of genetic modification.
4.4.11 Define *clone*.
4.4.12 Outline a technique for cloning using differentiated animal cells.
4.4.13 Discuss the ethical issues of therapeutic cloning in humans.

Exploring DNA

DNA is at the very core of what gives animals and plants their uniqueness. We are now going to look at the astounding genetic techniques, developed in the past few decades, which enable scientists to explore and manipulate DNA. These include:

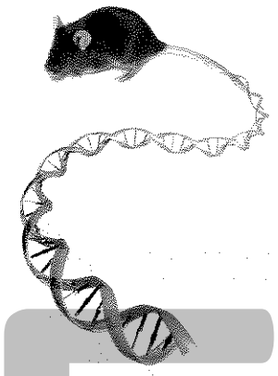
- copying DNA in a laboratory – the polymerasechain reaction (PCR);
- using DNA to reveal its owner's identity – DNA profiling;
- mapping DNA by finding where every A, T, C and G is – the Human Genome Project;
- cutting and pasting genes to make new organisms – gene transfer;
- cloning cells and animals.

These techniques offer new hope for obtaining treatments and vaccines for diseases; for creating new plants for farmers; for freeing wrongly convicted people from prison (thanks to DNA tests proving their innocence).

Techniques such as gene transfer and cloning have sparked heated debate. Is it morally and ethically acceptable to manipulate nature in this way? Are the big biotech companies investing huge sums of money into this research to help their fellow citizens or are they just in it for the economic profit? Concerning cloning and stem cell research, is it morally and ethically acceptable to create human embryos solely for scientific research?

Part of being a responsible citizen is making informed decisions relating to these difficult questions. It is not just technical complexity that makes these questions difficult, it is also because humans have never had to face them before.

Look at this image. What do you think about the idea expressed in the caption?



Genetic engineering allows living organisms to be considered in a new light, as libraries of DNA.

Polymerase chain reaction (PCR)

PCR is a laboratory technique which takes a very small quantity of DNA and copies all the nucleic acids in it to make millions of copies of the DNA (see Figure 4.9). PCR is used to solve a very simple problem: how to get enough DNA to be able to analyse it.

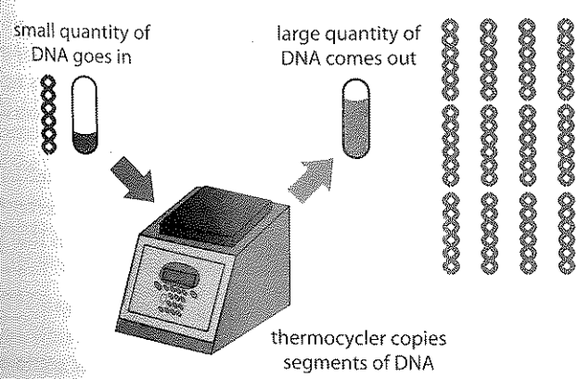


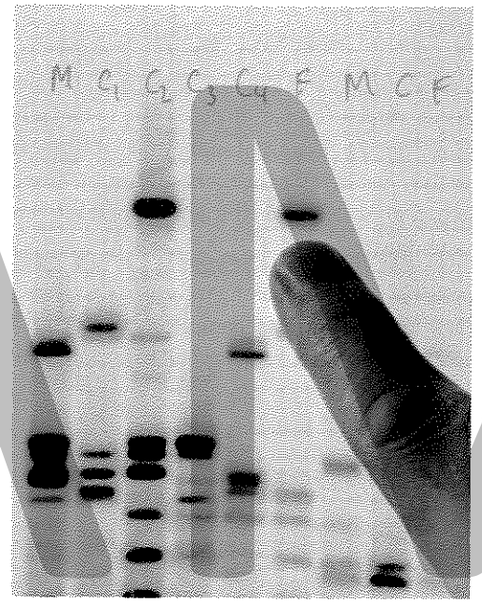
Figure 4.9 Analysis is impossible with the DNA from just one or a few cells. PCR is a way of ensuring that enough DNA for analysis can be generated.

When collecting DNA from the scene of a crime or from a cheek smear, often only a very limited number of cells are available. By using PCR, forensics experts or research technicians can obtain millions of copies of the DNA in just a few hours. Such quantities are large enough to get results from, notably using gel electrophoresis (see overleaf).

Gel electrophoresis

This laboratory technique is used to separate fragments of DNA in an effort to identify its origin. Enzymes are used to chop up the long filaments of DNA into varying sized fragments. The DNA fragments are placed into small wells (holes) in the gel which are aligned along one end. The gel is exposed to an electric current – positive on one side and negative on the other.

The effect is that the biggest, heaviest and least charged particles do not move easily through the gel so they get stuck very close to the wells they were in at the origin. The smallest, least massive and most charged particles pass through the gel to the other side with little difficulty. Intermediate particles are distributed in between. In the end, the fragments leave a banded pattern of DNA like the one shown in the photograph.



These banded lines were formed from nine different DNA samples during gel electrophoresis.

DNA profiling

The process of matching an unknown sample of DNA with a known sample to see if they correspond is called DNA profiling. This is also sometimes referred to as DNA fingerprinting because of some of the similarities with identifying fingerprints but the techniques are very different.
If, after separation by gel electrophoresis, the pattern of bands formed by two samples of DNA fragments are identical, it means that both most certainly came from the same individual. If the patterns are similar, it means that the two individuals are most probably related.

Applications of DNA profiling

DNA profiling can be used in paternity suits when the identity of someone's biological father must be known for legal reasons.

At a crime scene, forensics specialists can collect samples such as blood or semen which contain DNA. Gel electrophoresis is used to compare the collected DNA with that of suspects. If they match, the suspect has a lot of explaining to do. If not, the suspect is probably not the person wanted for the crime. Criminal cases are sometimes reopened many years after a judgement in order to consider new DNA profiling results. In the United States, this has lead to the liberation of many individuals who had been wrongly sent to jail for crimes they did not commit.

DNA profiling is used in other circumstances too. For example, in studies of ecosystems, when scientists use DNA samples taken from birds, whales and other organisms to clarify which individuals are related. This has helped establish a better understanding of social relationships, migrating patterns and nesting habits. In addition, the study of DNA in the biosphere has given new credibility to the ideas of evolution: DNA evidence can often reinforce previous evidence of common ancestry based on anatomical similarities between species.

How DNA profiles are analysed

In the photo showing gel electrophoresis of nine samples of DNA (page 102) the line marked C_2 (child number 2) and the one being pointed to, F (father), show similarities in their banding patterns. However, the children marked C_1, C_3 and C_4 do not show many similarities.

From this DNA evidence, it should be clear that person F is much more likely to be the father of child number 2, than of any of the other children. Similar techniques are used to analyse the similarities and differences between DNA collected at a crime scene and DNA samples taken from suspects.

The techniques have been perfected to a point where it is possible to determine the identity of someone by examining cells found in the traces of saliva left on the back of a postage stamp on a letter.

The Human Genome Project

In 1990, an international cooperative venture called the Human Genome Project set out to sequence the complete human genome. Because the genome of an organism is a catalogue of all the bases it possesses, the Human Genome Project hoped to determine the order of all the bases A, T, C and G in human DNA. In 2003, the Project announced that it had succeeded in achieving its goal. Now, scientists are working on deciphering which sequences represent genes and which genes do what. The human genome can be thought of as a map which can be used to show the locus of any gene on any one of the 23 pairs of chromosomes.

As you have seen, some diseases are sex linked, so it is relatively easy to determine which chromosome the gene responsible for the disease is found on; often the locus is on the X chromosome. In traits which show no sex linkage, it is difficult to know which of the 22 other chromosomes carries the gene. With genome libraries of genetic diseases, doctors can find out exactly where to look if they think one of their patients might possess a disease-carrying allele.

Another advantageous use of the human genome is the production of new medications. This idea involves several steps:
- find beneficial molecules which are produced naturally in healthy people;
- find out which gene controls the synthesis of a desirable molecule;
- copy that gene and use it as instructions to synthesize the molecule in a laboratory;
- distribute the beneficial molecule as a new medical treatment.

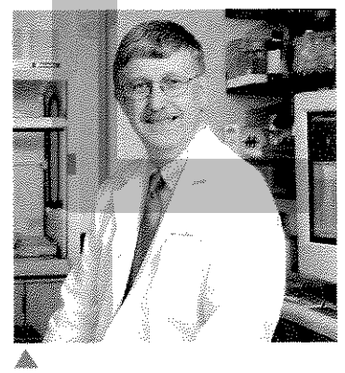
This is not science fiction; genetic engineering firms are finding such genes regularly.

- How do you think you would feel if you were to find out from DNA profiling that your father was not your biological father?
- How would a man feel if he found out he was not the child's father?
- What effect would such a result have on the relationships between siblings or between spouses?
- What kind of emotions might someone feel after spending 18 years in prison, and then being freed thanks to a DNA test?

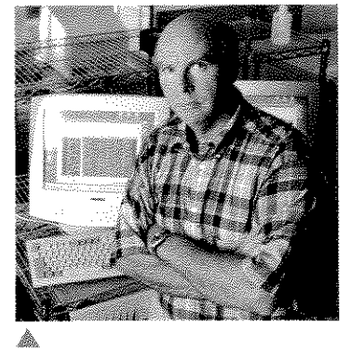
For many years, tests for blood groups were done to determine paternity. In what ways do you think DNA profiling is more reliable than a blood test?

Is it possible for two people to have the same DNA profile? The technique does not look at individual base sequences of A, T, C, G – only at clumps of sequences. Do you think it is possible to calculate the chances that two people have the same profile?

Should 100% confidence be placed in DNA testing? Do you think it would be right to convict a person solely on DNA evidence?



Dr Francis Collins, one of the leaders of the Human Genome Project team.



Dr Craig Venter, one of the leaders of the Human Genome Project team.

The Human Genome Project gives a new facet to the philosophical question, 'What does it mean to be human?' Can humanity be reduced to a sequence of nitrogenous bases represented as A, T, G and C? The figure of 98.5% is often given to describe how much DNA humans have in common with chimpanzees but research in 2002 revealed that it is probably more like 95%. In any case, both species have strikingly similar genomes but that does not make chimps human.

There is also the question of intellectual property. Theoretically, the information in the human genome should belong to everyone. Yet some private biotech research companies have patented genes they have found along the sequence of the human genome, claiming that since they found what the gene codes for, they should have the legal intellectual rights to the use of that gene in biotechnology. This means that if other laboratories wanted to use the genes, they would have to pay a royalty or licensing fee. Do you think this is right?

In addition, by comparing the genetic makeup of populations around the world, countless details could be revealed about ancestries and how humans have migrated and mixed their genes with other populations over time. Without knowing it, you are carrying around in each one of your cells a library of information about your past.

Delving into human genetics confirms two major themes:

- we are all the same;
- we are all different.

On the one hand, the Human Genome Project shows that there is a very small number of DNA bases which make one person different from any other person in the world. This creates a feeling of unity, of oneness with all people. From peanut farmers in West Africa to computer technicians in California to fishermen in Norway to businesswomen in Hong Kong, all humans carry inside them a common genetic heritage.

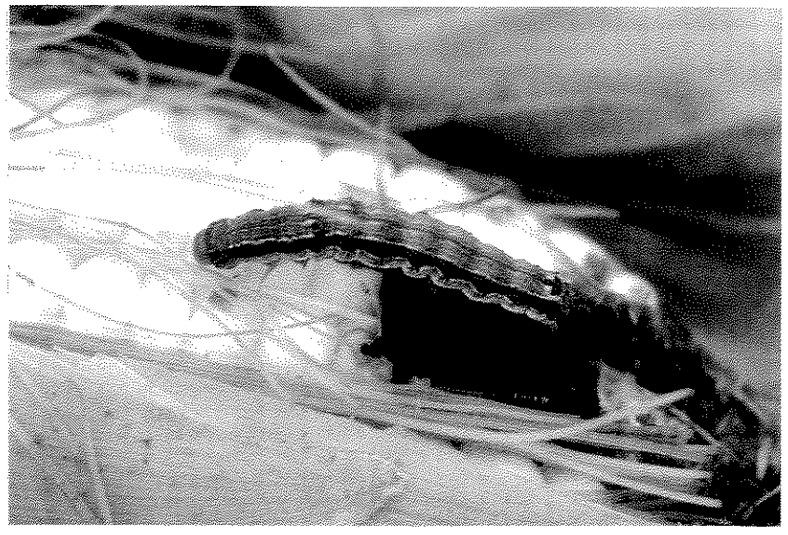
On the other hand, the human genome shows that the small differences which do exist are important ones which give each person his or her uniqueness in terms of skin colour, facial features or resistance to disease. These differences should be appreciated and celebrated as strengths. Unfortunately, they are often the basis of discrimination and misunderstanding.

Can one genetic group be considered genetically superior to another? History has shown that many people think so, yet genetics shows that this is not the case. All human populations, whatever slight differences their genomes may have, deserve equal esteem as human beings.

Gene transfer

The technique of taking a gene out of one organism (the donor organism, e.g. a fish) and placing it in another organism (the host organism, e.g. a tomato) is a genetic engineering procedure called gene transfer. Just such a transfer was done to make tomatoes more resistant to cold and frost.

It is possible to put one species' genes into another's genetic makeup because DNA is universal: as you will recall (Chapter 3, page 63), all known living organisms use the bases A, T, C and G to code for proteins. The codons they form always code for the same amino acids, so transferred DNA codes for the same polypeptide chain in the host organism as it did in the donor organism. In the example above, proteins used by fish to resist the icy temperatures of arctic waters are now produced by the modified tomatoes to make them more resistant to cold.



Another example of gene transfer is found in Bt-corn, which has been genetically engineered to produce toxins that kill the bugs which attack it. The gene, as well as the name, come from a soil bacterium, *Bacillus thuringiensis*, which has the ability to produce a protein that is fatal to the larvae of certain crop-eating pests.

Pests such as this corn earworm are responsible for reduced yields in traditional corn crops.

The manipulation of genes raises some challenging questions. For many of these questions, there is not enough conclusive scientific data to reach a satisfactory answer.

- Is it ethically acceptable to alter an organism's genetic integrity?
- If the organism did not have that gene in the first place, could there be a good reason for its absence?
- Why are people so worried about this new technology? In selective breeding, thousands of genes are mixed and matched. With GMOs, only one gene is changed. Is that not less risky and dangerous than artificial selection?
- Would strict vegetarians be able to eat a tomato which has a fish gene in it?
- Does research involving GM animals add a whole new level to animal cruelty and suffering in laboratories?
- If Bt-crops kill insects, what happens to the local ecosystem which relies on the insects for food or pollination?

Cutting, copying and pasting genes

Although the laboratory techniques are complex, the concepts are not difficult.

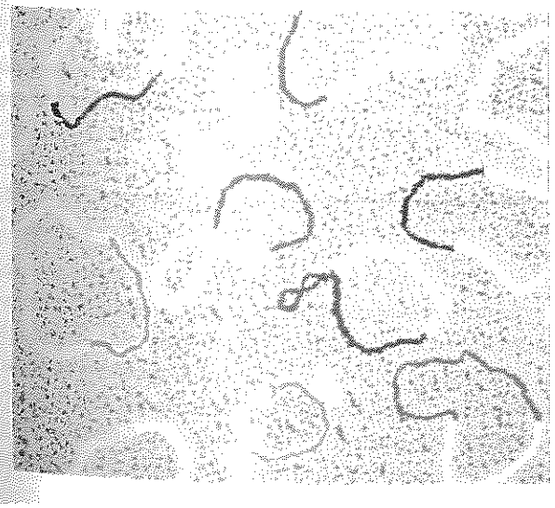
Cutting and pasting DNA

The 'scissors' used for cutting base sequences are enzymes. Restriction enzymes called endonucleases find and recognize a specific sequence of base pairs along the DNA molecule. Some can locate target sequences which are sets of four base pairs, others locate sets of six pairs. The endonucleases cut the DNA at specified points. If both the beginning and the end of a gene are cut, the gene is released and can be removed from the donor organism. For pasting genes, the enzyme used is called DNA ligase. It recognizes the parts of the base sequences that are supposed to be clicked together, called the sticky ends, and attaches them.

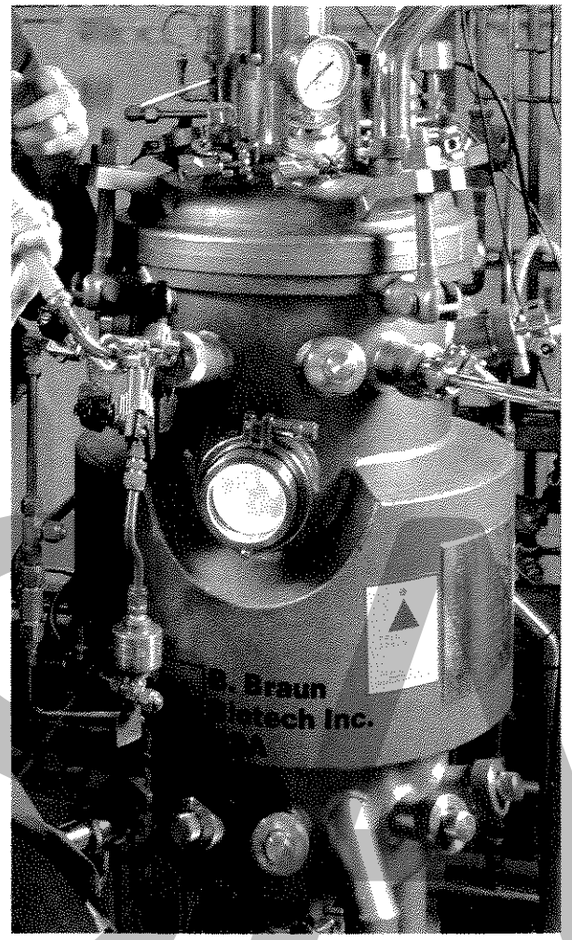
Copying DNA (DNA cloning)

This is more complex because a host cell is needed in addition to the cutting and pasting enzymes described above. Although yeast cells can be used as host cells, the most popular candidate in genetic engineering is the bacterium *Escherichia coli.*

Like other prokaryotes, most of the genetic information for *E. coli* is in the bacterium's single chromosome. However, some DNA is found in structures called plasmids. Plasmids are small circles of extra copies of DNA floating around inside the cell's cytoplasm. To copy a gene, it must be glued into a plasmid.



This is a false-colour electronmicrograph of plasmids.



This is a bioreactor and is used to grow bacteria which have recombinant DNA.

To do this, a plasmid is removed from the host cell and cut open using a restriction endonuclease. The gene to be copied is placed inside the open plasmid. This process is sometimes called gene splicing. The gene is pasted into the plasmid using DNA ligase. The plasmid is now called a recombinant plasmid and it can be used as a vector, a tool for introducing a new gene into an organism's genetic makeup.

In the final step needed for copying (or cloning) the gene, the vector is placed inside the host bacterium and the bacterium is given its ideal conditions to grow and proliferate. This is done by putting the bacterium into a bioreactor, a vat of nutritious liquid kept at a warm temperature.

Not only does the host cell make copies of the gene as it reproduces, but since the gene is now in its genetic makeup, the modified *E. coli* cell expresses the gene and synthesizes whatever protein the gene codes for. This process has been used successfully in getting *E. coli* to make human insulin, a protein needed to treat diabetes (Chapter 6, page 184). The older technique for obtaining insulin involves extracting it from cow and pig carcasses generated by the meat industry, but this has caused allergy problems. Using recombinant human DNA avoids that problem.

Genetically modified organisms

A genetically modified organism (GMO) is one that has had an artificial genetic change using the techniques of genetic engineering such as gene transfer or recombinant DNA described above. One of the main reasons for producing a genetically modified organism is for it to be more competitive in food production.

Transgenic plants

The simplest kind of GM food is one in which an undesirable gene is removed. In some cases, another more desirable gene is put in its place but in other instances, only the introduction of a new gene is needed, no DNA has to be removed.

Whichever technique is applied, the end result is either that the organism no longer shows the undesired trait or that it shows one which genetic engineers want. The first commercial example of a GM food was the 'Flavr Savr' tomato. It was first sold in the US in 1994 and had been genetically modified to delay the ripening and rotting process so that it would stay fresher longer. Although it was an ingenious idea, the company lost so much money from the project that it was abandoned a few years later.

Another species of tomato was modified by a bioengineering company to make it more tolerant to higher levels of salt in the soil. This makes it easier to grow in certain regions of high salinity. One of the claims of the biotech industry is that GM foods will help solve the problem of world hunger by allowing farmers to grow foods in various otherwise unsuitable conditions. Critics point out that the problem of hunger in the world is one of food distribution, not food production.

One company controls nearly all of the worldwide GM market. To grow their GM crops, farmers must pay a yearly licensing fee to the company. The same company sells the herbicides which are compatible with the GM plants.

This raises concerns that too much economic power will be in the hands of one corporation. What effects will this have on farmers and on local economies?

Another plant of potential interest to the developing world is a genetically modified rice plant which has been engineered to produce beta carotene in the rice grains. The aim is that the people who eat this rice will not have deficiencies in vitamin A (the body uses beta carotene to form vitamin A).

Transgenic animals

One way of genetically engineering an animal is to get it to produce a substance which can be used in medical treatment. Consider the problem faced by some people with haemophilia – a blood condition in which their blood does not clot because they lack a protein called factor IX. If such people can be supplied with factor IX, their problem will be solved. The least expensive way of producing large amounts of factor IX is to use transgenic sheep. If a gene which codes for the production of factor IX is associated with the genetic information for milk production in a female sheep, she will produce that protein in her milk.

In the future, a wide variety of genetic modifications may be possible. Perhaps inserting genes to make animals more resistant to parasites, to make sheep produce pre-dyed wool of any chosen colour, to produce prize-winning show dogs, faster racehorses … the possibilities seem almost boundless and it is difficult to imagine what the future might be like.

Is genetic engineering a good or a bad thing?

Genetic engineering raises many profound social and ethical questions. As you read through the ideas below, note which ones you agree with. Can you justify your opinions?

Benefits, promises, and hopes for the future

- GM crops will help farmers by improving food production.
- GM crops which produce their own pest-control substances will be beneficial to the environment because fewer chemical pesticides will be needed.
- Using GMOs to produce rare proteins for medications or vaccines could be, in the long run, less costly and produce less pollution than synthesizing such proteins in laboratories.
- Farmers can be more in control of what crops or livestock they produce. There is always some randomness in breeding; genetic modification makes the process less of a gamble. It is also much quicker than selective breeding.
- The multinational companies who make GM plants claim that they will enable farmers in developing nations to help reduce hunger by using pest-resistant crops or GM plants which require less water.

Harmful effects, dangers, and fears

- No one knows the long-term effects of GMOs in the wild. Efforts to keep GM plants under control in well-defined areas have failed and pollen from GM crops has escaped to neighbouring fields. Genes from GM plants could be integrated into wild species giving them an unnatural advantage over other species and an ability to take over the habitat.
- There is a danger that the genes could cross species. It has been proven possible in laboratories, so there is a possibility in nature too. Again, no one knows the consequences of genes crossing species.

Is altering a plant or animal's DNA justified by the benefit that it may bring to humans? Just how far is it acceptable to go in manipulating a species' genes? Should experiments be stopped if they start to modify the ecosystems they are in? Who should decide?

If there are risks associated with GM plants and animals, should all research and experiments be banned? How is it possible to know how severe the risks are? In order to assess the risks, experiments need to be done. The experiments themselves, however, present risks.

The technology is so complex that it is often difficult for scientists to explain what the risks are to farmers, consumers and lawmakers. As a result, it is a challenge for all citizens to make an educated decision about whether or not GM foods are safe to eat and safe for the environment. Without complete information, it is easy to fall into the trap of irrational fear or complete apathy.

Some groups who have made up their minds that GM crops are dangerous have decided to destroy the plants in the fields where they are being grown and tested. Does such action make the world a safer place?

- Bt-crops which produce toxins to kill insects could be harmful to humans because, unlike chemical pesticides which are only applied to the outer surface, the toxins are found throughout the plant.
- There are risks for allergies: if someone is not allergic to natural tomatoes but is allergic to GM tomatoes, they will need to know which one they are eating. But there is no difference in the outward appearance of the fruit and food labelling is not always clear.
- Critics are worried that large portions of the human food supply will be the property of a small number of corporations.
- High-tech solutions are not necessarily better than simpler solutions. Crop production could be increased by teaching farmers how to use water and natural pest-control systems more efficiently.
- A proliferation of genetically modified organisms may lead to a decrease in biodiversity.

Clones and cloning

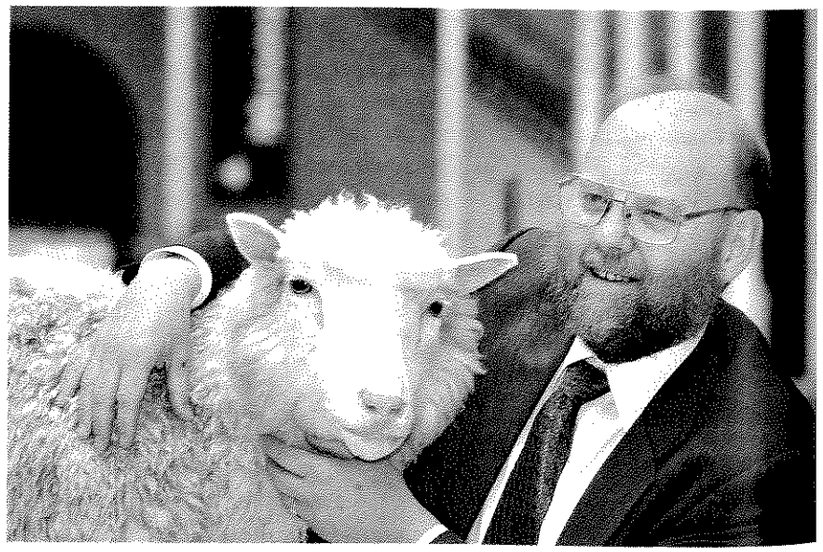
The definition of a clone is a group of genetically identical organisms or a group of cells artificially derived from a single parent. In either case, the resulting cells or organisms were made using laboratory techniques. In farming, clones have been made for decades by regenerating plant material or by allowing an in-vitro fertilized egg to divide to make copies of itself.

Until recently, cloning was only possible using genetic information from an egg cell. Fertilized eggs are not differentiated (specialized) yet. After dividing many times, some of the cells will specialize into muscle cells, others into nerves, others into skin and so on until a fetus forms. For a long time, it was thought that once a cell has gone through differentiation, it cannot be used to make a clone. But then there was Dolly.

Cloning using a differentiated animal cell

In 1996, a sheep by the name of Dolly was born. She was the first clone whose genetic material did not originate from an egg cell. Here is how researchers at the Roslin Institute in Scotland produced Dolly (see also Figure 4.10).

This is Dolly with Ian Wilmut, a member of her cloning team.



1 From the original donor sheep to be cloned, a somatic cell (non-gamete cell) from the udder was collected and cultured. The nucleus was removed from a cultured cell.
2 An unfertilized egg was collected from another sheep and its nucleus was removed.
3 Using a zap of electrical current, the egg cell and the nucleus from the cultured somatic cell were fused together.
4 The new cell developed in vitro in a similar way to a zygote and started to form an embryo.
5 The embryo was placed in the womb of a surrogate mother sheep.
6 The embryo developed normally.
7 Dolly was born, and was presented to the world as a clone of the original donor sheep.

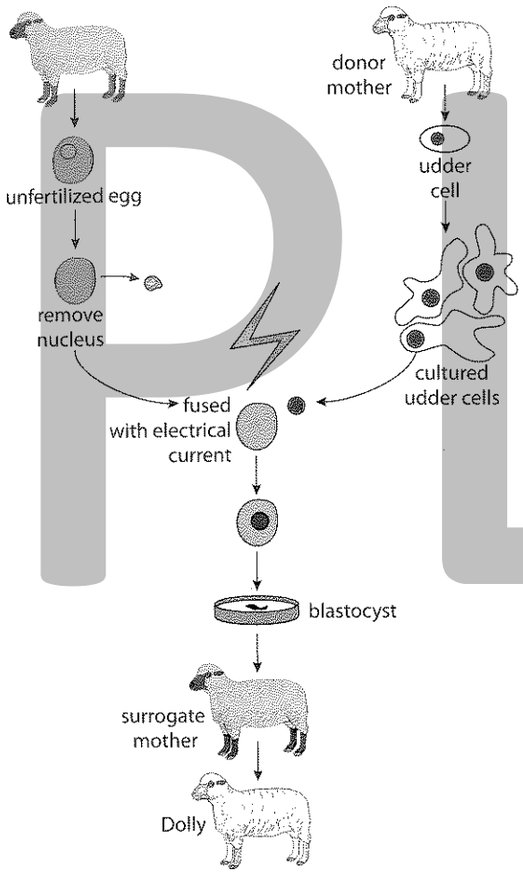


Figure 4.10 The step-by-step process of how the clone Dolly was made.

This kind of cloning is called reproductive cloning because it makes an entire individual.

Cloning using undifferentiated cells

In some cases, scientists are not interested in making an organism but simply in making copies of cells. This second type of cloning is called therapeutic cloning and its aim is to develop cells which have not yet gone through the process of differentiation. Since the first technique in this area involved using embryos, the cells are referred to as embryonic stem cells, and the branch of lab work which investigates therapeutic cloning is called stem cell research.

The idea of cloning often provokes strong negative reactions from people, especially when the only information they have comes from science fiction or horror films.

When making ethical decisions about what is good and bad, or right and wrong, it is important to be as well informed as possible.

In dealing with the ethical issues of cloning, it should be stressed that there are two distinct forms of cloning:

- reproductive cloning – making copies of entire organisms;
- therapeutic cloning – making copies of embryonic stem cells.

Some people think that both are unacceptable, others think both are fine and some are in favour of one but not the other. Where do you stand?

Ethical issues surrounding therapeutic cloning

Since therapeutic cloning starts with the production of human embryos, it raises fundamental issues of right and wrong. Is it ethically acceptable to generate a new human embryo for the sole purpose of medical research? In nature, embryos are created only for reproduction and many people believe that using them for experiments is unnatural and wrong.

However, the use of embryonic stem cells has lead to major breakthroughs in the understanding of human biology. What was once pure fiction is coming closer and closer to becoming an everyday reality thanks to stem cell research:

- growing skin to repair a serious burn;
- growing new heart muscle to repair an ailing heart;
- growing new kidney tissue to rebuild a failing kidney.

With very rare exceptions, the vast majority of researchers and medical professionals are against the idea of reproductive cloning in humans. However, there is a growing popularity for the pursuit of therapeutic cloning since the promises of stem cell research are so enticing.

Exercises

14 Explain why PCR is necessary.

15 Explain the central ethical issue concerning stem cell research.

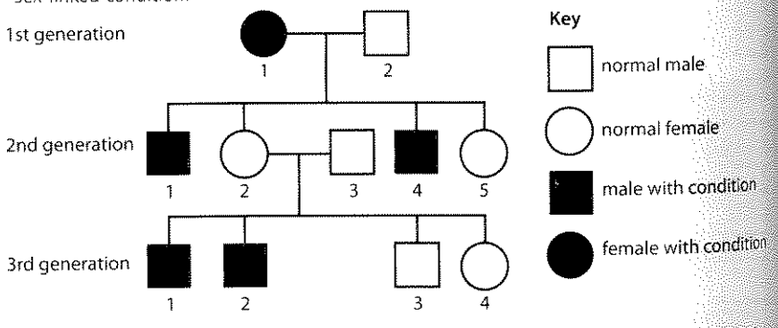
16 Justify whether the benefits outweigh the risks in genetically modifying plants and animals.

17 Look at the foods in your house. Are food labels today effective at indicating when and how much of the food is genetically modified? Justify your answer.

Practice questions

1 Describe the consequence of a base substitution mutation with regards to sickle cell anaemia. *(7 marks)*

2 The diagram below shows the pedigree of a family with red–green colour blindness, a sex-linked condition.



(a) Define the term *sex linkage*. *(1)*

(b) Deduce, with a reason, whether the allele producing the condition is dominant or recessive. *(2)*

(c) **(i)** Determine all the possible genotypes of the individual (2nd generation – 1) using appropriate symbols. *(1)*

(ii) Determine all the possible genotypes of the individual (3rd generation – 4) using appropriate symbols. *(1)*

(Total 5 marks)

3 Outline the differences between the behaviour of the chromosomes in mitosis and meiosis. *(5 marks)*

4 **(a)** Define the term *codominance*. *(1)*

(b) A man of blood type AB and a woman of blood type B are expecting a baby. The woman's mother had blood type O. Deduce the possible phenotypes of the offspring from the cross. Include the parents' genotypes, the gametes, the F1 genotypes and the F_1 phenotypes. *(4)*

(Total 5 marks)

5 Discuss the potential benefits and possible harmful effects of genetic modification. *(7)*

6 Outline DNA profiling (genetic fingerprinting), including one way in which it has been used. *(5)*

7 Karyotyping involves arranging the chromosomes of an individual into pairs. Describe one application of this process, including the way in which the chromosomes are obtained. *(5)*